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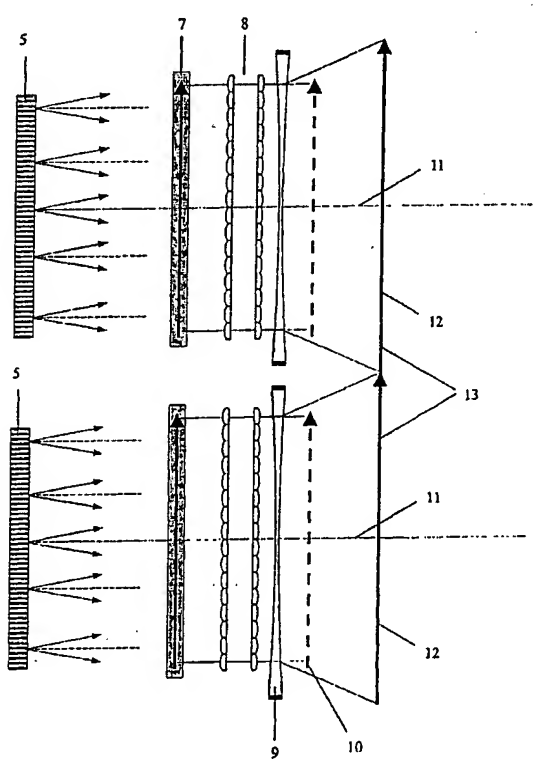
(54) Title: PHOTOLUMINESCENT LIQUID CRYSTAL DISPLAY



(57) Abstract: A display includes a point source (1, 5) of activation radiation, or an array of such sources, a lens system (3) for collimating the radiation from the point source or array, a modulator (7) capable of controlling the transmission of the collimated excitation radiation, and a screen (13) capable of emitting a visible display when struck by the modulated activation radiation and since the light is produced by point sources, such as LEDs, accurate collimation can be achieved with no loss. This in turn means that the modulated light can be expanded to produce a seamless tiled display.

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PHOTOLUMINESCENT LIQUID CRYSTAL DISPLAY

The invention concerns liquid-crystal displays of the type shown for instance in WO 97/27920 (Crossland et al.) where excitation light, usually in the near-UV range, is modulated by a liquid-crystal cell before falling onto a phosphor screen which produces visible light for the display. The phosphor screen can be made of RGB dots which give a colour display very much like that of a CRT, while still preserving the flat-panel format.

A problem with this kind of display is that the ultra-violet light passing through each pixel of the liquid-crystal cell has to strike the corresponding phosphor dot, since otherwise the image will be distorted or ghosted. A means of avoiding this and of allowing high resolution is to use highly collimated input radiation. However, a high degree of collimation usually means a corresponding loss in energy efficiency.

Hitherto the sources of UV light for UV-LCDs have been discharge tubes coated with phosphors emitting in the near-visible ultra-violet. These are of course lambertian emitters and need fairly complex collimation or filtering arrangements to produce any kind of collimated source - see for instance WO 98/49585 (Screen Technology Limited). Recently UV light-emitting diodes have become available and these have been used as sources for multicolour fluorescent LCDs. See the article "Fluorescent liquid-crystal display using a UV light emitting diode" by Yamaguchi et al., IDW 98 pages 25 to 28. The LEDs emit at about 372 nm. However, they are simply used as a somewhat more compact replacement for a fluorescent tube.

According to the invention there is provided a liquid-crystal display including a point source of

excitation light, a lens system for collimating light from the point source into a beam, a light modulator, such as a liquid-crystal cell, capable of modulating the light beam, and a screen capable of emitting a visible display when struck by the modulated excitation light.

By "collimated light" a person skilled in the art will understand a beam or beams of light in which substantially all of the rays are contained within a preferred angular range. It is common to describe this range as a "cone angle". Typical values of the half-angle of the cone are 4-10 degrees, but they are not limited to this range. The preferred cone angle will be determined by the several properties of the optical elements (modulator and lenses) in the display system, and by the goal of maximum energy efficiency.

The point source can be a light-emitting or laser diode emitting preferably in the range 350-450 nm, and the screen can include phosphor or similar material, preferably arranged in an RGB colour triad formation. There can be several such point sources each with its own collimating lens to form a large-area display. Whereas LEDs often have highly divergent or diffusing optics, e.g. for lamps, this invention uses optics of low divergence substantially to preserve the point-source nature of the emission area.

The collimated light produced in such an arrangement can be used with a single liquid-crystal cell; however it is of particular advantage when it is desired to tile several such cells. Tiling is desirable in order to form large displays to overcome the size limitation of current liquid crystal fabrication and to enable the production of liquid-crystal-based displays with diagonals greater than 40 inches (100 cm) at low cost.

A way of reducing the sensitivity of positioning

of the phosphor elements of the output screen, or conversely of increasing the resolution of the display, is disclosed in WO 00/17700 (Screen Technology Ltd.). Here, instead of light passing through the liquid-crystal cell simply being allowed to fall on the screen, it is focussed through an intermediate array of lenses, such as microlenses, so that an image of the liquid-crystal plane is formed on the screen. However, this system is still vulnerable to defects caused by input light that is not adequately collimated. If the radiation from the modulation layer is not sufficiently collimated then some light passing through a lens in one array of lenses will not pass through an associated lens in the next array resulting in cross-talk between the two lens trains which will result in secondary imaging that will decrease the quality of the image. This can in principle be prevented irrespective of the degree of collimation, i.e. even with a lambertian source, by having baffles or vignetting between adjacent microlenses and using field lenses. However, this is expensive, will reduce the efficiency of throughput of the optical system and may be impractical to make commercially. With the present invention, light can be input to the liquid-crystal sufficiently collimated that such baffles may not be necessary in the optical imaging system.

Moreover, if the optical arrangement between liquid-crystal cell and screen is such that it magnifies the image from the liquid-crystal slightly, as is also disclosed in WO 00/17700, then several such images from adjacent panels or cells can be tiled to form a composite larger image, or so-called seamless tiling of images, as mentioned above. Such magnification can be achieved for instance by the use of Gabor superlenses, i.e. two parallel arrays of microlenses of slightly different pitch, or a

combination of micro-lens arrays and a larger optic that can be a Fresnel-type structure or a diffractive element such as a Bragg hologram as will be discussed in the embodiments.

For a better understanding of the invention, and by way of example only, embodiments will now be described with reference to the accompanying drawings, in which:

Figures 1a and 1b show LED light sources such as can be used in embodiments of the invention;

Figure 2 shows two versions of a first embodiment of the invention, with and without magnification;

Figure 3 shows a system using the first embodiment with slight magnification enabling tiling.

Figure 4 shows a second embodiment; and

Figure 5 shows a complete system.

Figure 1a shows a schematic of a common example of a small-area source in the form of an LED. A relatively small emission centre 1 is directly stimulated to emission by an electrical power source 2. The emission occurs within an encapsulating transparent lens structure 3 that, because of the relative apertures between the emitter 1 and the optic 3, produces a substantially collimated output 4. Note that this represents the simplest and most common form of collimation for such a source (i.e. one simple optical surface after a quasi-point source) but is not necessarily that which would be used in the context of this invention.

It is the purpose of embodiments of this invention to maintain this high degree of collimation and to utilise a larger-area backlight 5 such as depicted schematically in **Figure 1b** where the output from the backlight 5 has the same or very nearly the same angular distribution as the original collimation 4

achievable over an extended area 6. The backlight receives its radiant flux from either a single high-energy point source or an array of such sources. This distribution allows the efficient use of arrays of optics in the PL-LCD (photoluminescent LCD) architecture to form single or tiled high-resolution displays. In particular, large-area displays can be formed by seamlessly tiling more than one modulating component. The problems associated with the imaging required are alleviated by the use of hitherto unavailable small-area (and hence capable of being efficiently collimated) sufficiently intense emitters with suitable emission bandwidths.

The situation depicted in Figure 1a is the simplest possible and is shown here to illustrate the collimation possible due to the relative apertures of the emitter 1 and the optic 3. The emitter 1 could be a close-packed array of emitters, for example, that use the same collimating optic because of the small size of their collective aperture. The optic 3 can take many more forms that are more suitable for use in a larger-area backlight such as that in Figure 1b. Any reflections the radiation would normally undergo in the course of producing an expansion of the collimated source should normally be specular, since this will not destroy the angular distribution as would diffuse reflection. The emitters may be surrounded by reflective cans that send the radiation forward, in the required direction towards the modulating layer, for example a liquid-crystal layer. Some of the light emitted from the source may not be of a wavelength suitable for PL-LCDs and may therefore have to be filtered, leaving the required excitation radiation that will energise the phosphors and produce the image at the screen.

Figure 2 shows a schematic for one embodiment that

in one version produces an enlarged image 12 of a modulating area 7 and in another products a one-to-one image.

In Figure 2, LEDs 1 in the backlight 5, each effectively being a point source, emit light at about 390 nm which is collimated by suitable lenses 3 into an adequately parallel beam which impinges upon the liquid-crystal panel 7. The liquid-crystal panel 7 is formed in the usual way with orthogonal electrodes (not shown), of which there are many within the path of the beam. The liquid-crystal material is adapted to modulate the ultra-violet light, and to this end may be of any known type, such as TN, STN, nematic/cholesteric phase transition or the like, with polarisers as appropriate. Instead of an LED a laser diode with appropriate diverging optics could be used, in which case it might be possible to dispense with one polariser.

Micro-optics that may be of conventional form and may be refractive, a Fresnel structure or diffractive are arrayed 8 to produce an erect one-to-one image 10 of the modulating layer 7. This image is formed on the far side of, and as such acts as a virtual object for, a negative magnifying optic 9 that may be refractive, a Fresnel structure or diffractive, thereby producing the erect real magnified image 12 on the phosphor layer in the PLLCD architecture. The magnification of the modulating layer 7, or of a block of its area to which the optics apply, is with respect to the global optical axis 11 for the block so that the enlarged image 12 is in line with the object block 7.

Obviously, if the power of the magnifying optic 9 is zero, or it is removed, then the one-to-one image 10 is a real image and the information can be viewed on a phosphor screen placed to coincide with the image. This is the case where a high-resolution image is

required from one block or modulating panel only.

In preferred embodiments the modulated beam, still highly collimated with a half-angle of divergence of, for example, 4-10°, is focussed by the array 8 of microlenses onto a screen covered with RGB phosphor dots. The microlenses might have diameters of between 0.5 mm and 3 mm with a focal length of the order of millimetres; the total thickness of the optical system might be of the order of 50 mm. Each microlens images an area of a number of pixels, conceivably even a single pixel, from the liquid-crystal panel 7 onto a corresponding number of phosphor pixels on the screen; because of the high degree of collimation of the light, there is no significant overlap of imaging from one set of liquid-crystal pixels onto the wrong area of phosphor pixels. For further details of composite imaging, as this scheme is called, reference may be made to the aforementioned WO 00/17700.

It is clear that several LED sources 1 can be arrayed with corresponding lenses 3 so as to form an extensive backlight for the system, although care must be taken in setting the lenses 3 into a two-dimensional array, because circular lenses will not fill the area. Diffractive optics might be one solution to this problem, the narrow-band nature of the light making possible an efficient use of such optical elements.

Figure 3 shows how two such magnified images 12 as described in Figure 2 can be seamlessly tiled to form a composite enlarged image on the screen 13. More than two such enlargements can be performed adjacently so that an array of images can be seamlessly tiled for a large-area display.

In Figure 3 several such LCD panels 7, 7' are assembled adjacent to each other to form a large plane, with enough space between each pair of panels for the wiring, seal and other edge components of each panel.

Each panel might be a rectangle 20 cm by 15 cm with a 1 cm space between the active optical components of each pair of adjacent panels. If the image of each panel is expanded by perhaps 5-10%, depending on the throw of the system, then the image on the phosphor screen, which can be a single screen or an assembly of butted-up screens, can be continuous and as large as is desired. There may be a limit in practice to the size of phosphor screen that it is possible to print with RGB dots, so the screen 13 can be divided into several portions each covering and receiving light from several panels 7. Alternatively each panel 7 can have its own screen 13 to form a self-contained module. In any event it is clear that screen portions can be butted up seamlessly because they do not have any need for electrode access or the like.

Figure 4 shows a second embodiment representing an alternative scheme for producing an enlarged image of a modulating block 7. In this embodiment a so-called SuperGabor lens is used. An array of lenses 14a with a certain pitch (separation within the array) is matched to a second array of lenses that have a slightly larger pitch 14b. In the simplest case the powers of all the lenslets are equal and they are positioned so that the tilts of the local optical axes 16 are such that the new image formed when radiation is imaged through the lenslet pairs along these local optic axes 16 is a magnified image 12 of the object plane 7 with respect to the global optic axis 11. For a properly registered composite image the magnification arising from each of the lens pairs must equal the global magnification.

To achieve a greater efficiency it may be desirable to diverge the collimated radiation of the object plane in such a way that it matches the gradual tilting of the optical axes 16. That is to say, the numerical aperture of the radiation leaving the

modulating layer is made to match that of the SuperGabor lens as much as possible. This can be achieved by placing a lens system 15 with a diverging lens function between the object plane and the first lenslet array 14a. As before, the elements in the arrays 14a and 14b and the single optical element 15 can be refractive or diffractive or have a Fresnel structure.

Figure 5 shows a schematic perspective view of a tiled display area or screen 13 formed from the magnification of an array of individual modulating blocks or panels 7 by imaging through an array of SuperGabor lenslet arrays (14a and 14b) for example. This is made efficient and cost-effective by the use of simple optics, in turn made viable by the existence of a highly collimated backlight 1b (of which only one panel is shown).

In summary, embodiments of the invention are concerned with utilising the degree of collimation made possible by the recent arrival and availability of sufficiently high-powered point sources in the range of wavelengths suitable for use in the PL-LCD architecture, i.e. those wavelengths that can be used to excite phosphors and that can be modulated (e.g. by a liquid crystal) in such a way that information can be displayed. The degree of collimation is maintained through the system and is altered only upon magnification of the object plane where it is imaged onto or arrives at a phosphor screen so as to produce an enlarged image, thereby allowing a continuous display screen to be formed from spatially separated individual modules or blocks of modulating areas. The use of the collimated radiation increases the contrast of the modulator; reduces the cross-talk between optical elements in arrays and between elements of the radiation from different pixels in the modulating layer

as they arrive on the phosphor screen; allows simpler and hence cheaper design of the arrayed optics (e.g. for many systems the lenslet can be simple-spherical in shape); minimises the distances due to the small nature of the optical elements and the high powers associated with them; and enables the production of a uniformity of irradiation of the phosphor screen by utilising lenslets of small dimensions such that radiation from a modulator pixel passes through several lens trains. The limited wavelength range of the small area emitters also aids in the optical design of the system.

CLAIMS

1. A display including a substantially point source (1, 5) of activation radiation, or an array of such sources, a lens system (3) for collimating the radiation from the point source or array, a modulator (7) capable of controlling the transmission of the collimated excitation radiation, and a screen (13) capable of emitting a visible display when struck by the modulated activation radiation.

2. A display according to claim 1 and further including a relay or imaging optical system between the modulator and the screen, for transferring the modulated radiation to the screen.

3. A display according to claim 2, in which the optical system expands the light beam without substantially reducing its degree of collimation.

4. A display according to claim 3, in which the optical system comprises a microlens pair array (8) and a diverging lens (9).

5 A display according to claim 3, in which the optical system comprises a diverging lens followed by a SuperGabor microlens pair array.

6. A display according to any preceding claim, in which the modulator is a liquid-crystal cell, the activation radiation is near-visible UV or short-wavelength visible light and the screen (13) is coated with RGB phosphors to produce a colour

display, the excitation spectra of the phosphors matching the wavelength(s) of the activation radiation.

7. A display according to any preceding claim, in which the point sources (1, 5) are LEDs or laser diodes, or arrays of such.

8. An assembly of displays according to claim 2 or any of its dependent claims, in which diverged images from each modulator or modulator block abut on the screen to produce a seamless image.

9. An assembly according to claim 8, in which blocks of the same modulator panel are imaged by several adjacent imaging systems.

10. An assembly according to claim 8 or 9, in which the screen (13) is monolithic or is composed of parts each receiving light from several modulator panels.

11. An assembly according to claim 8 or 9, in which the screen (13) is made of abutting modular screen portions corresponding to the modulators.

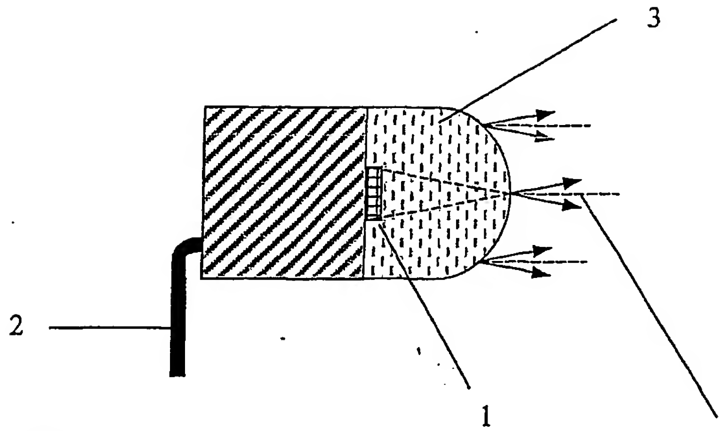

Figure 1a

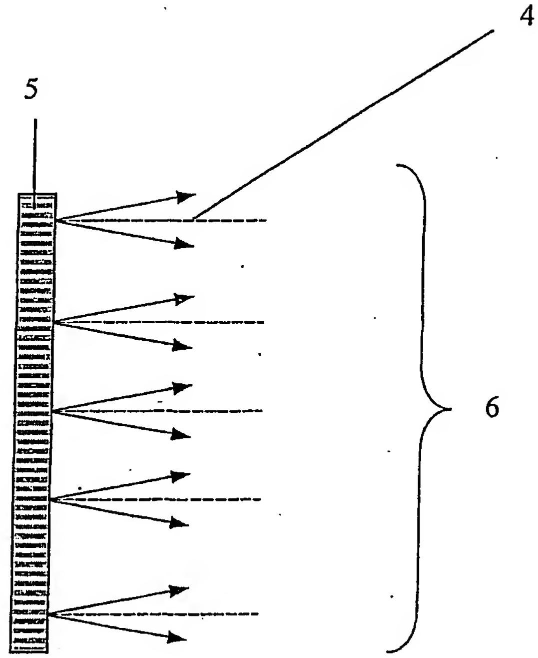

Figure 1b

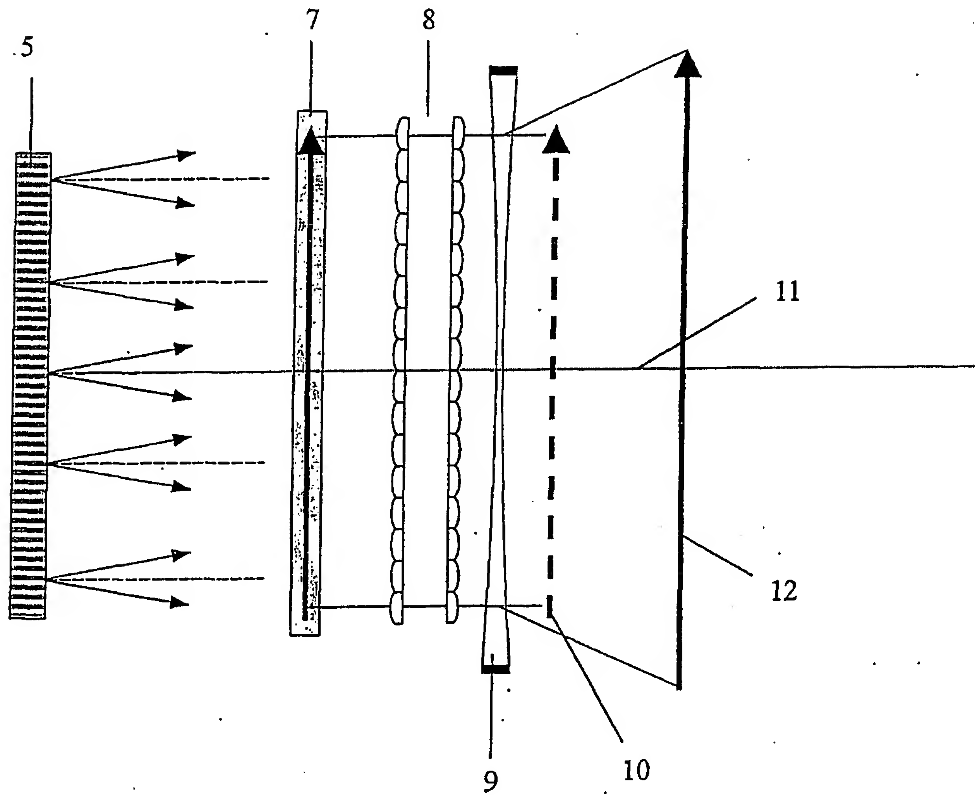

Figure 2

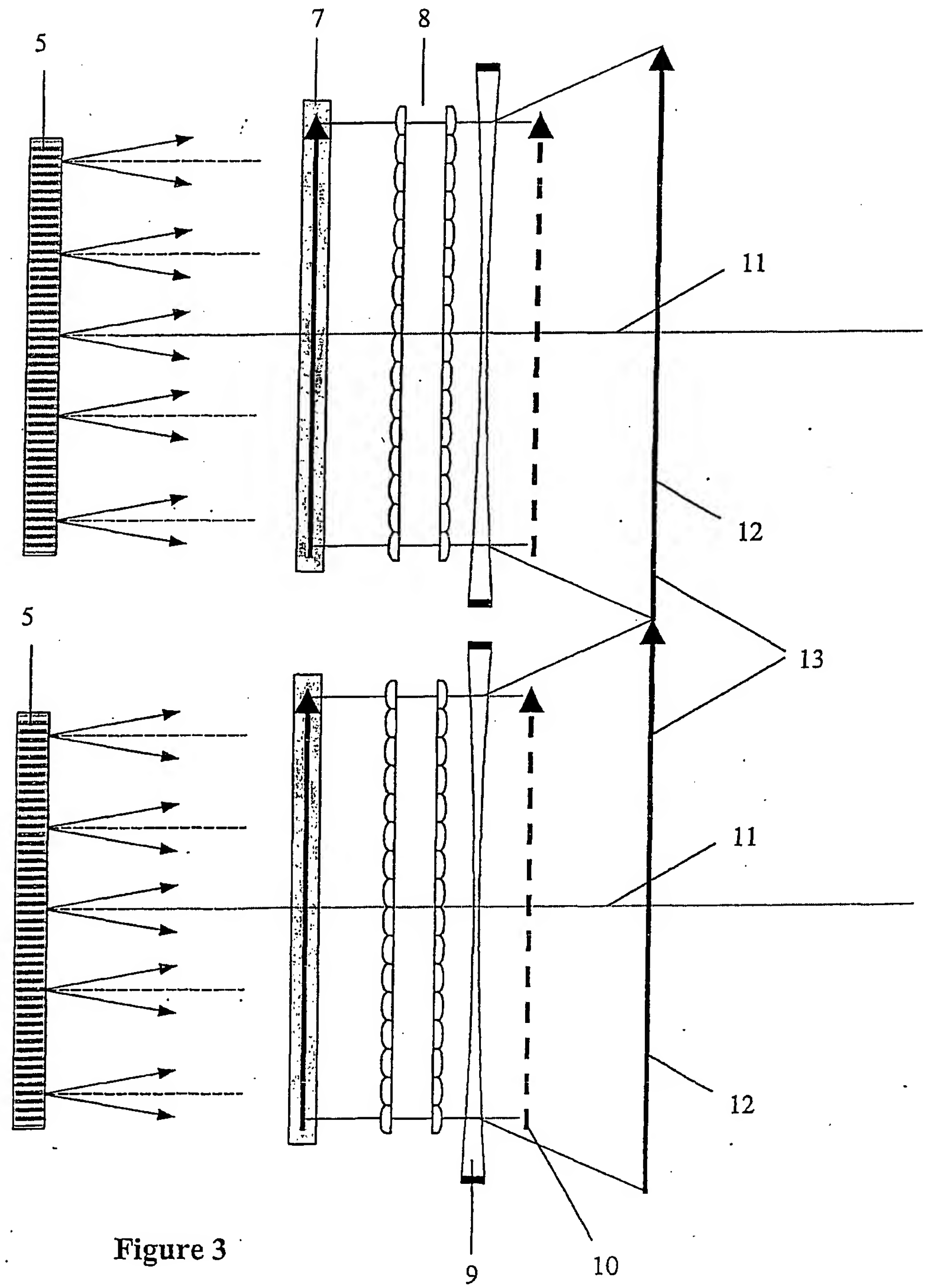

Figure 3

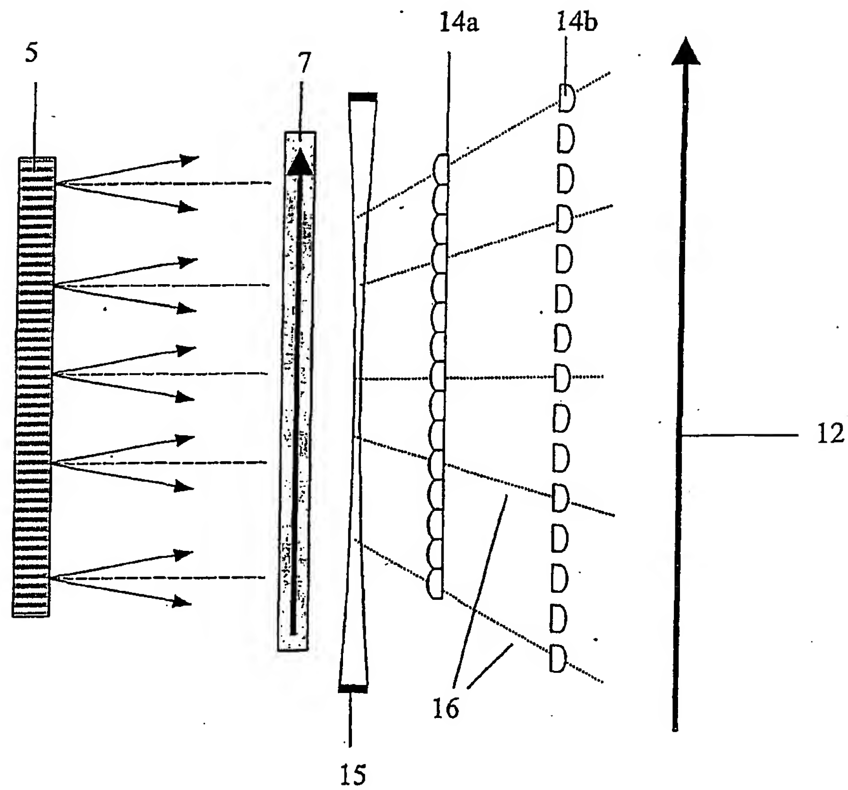

Figure 4

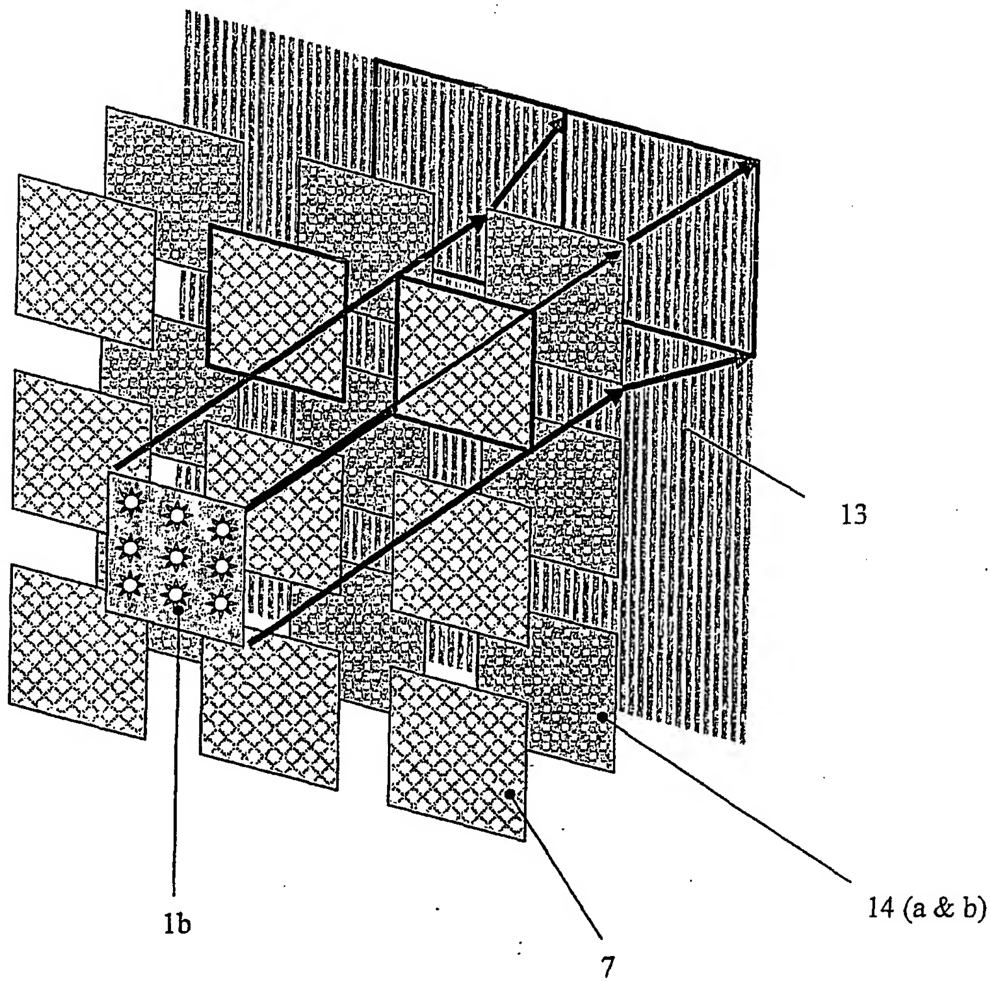

Figure 5

INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02F1/13357 G02F1/1335 F21V8/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02F F21V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	page 4, line 28 -page 7, line 36; figures 1,11 page 9, line 22 -page 11, line 25	4,5
Y	EP 1 003 064 A (SEIKO EPSON CORP) 24 May 2000 (2000-05-24) column 15, line 40 -column 16, line 26; figures 8,9 column 3, line 2 -column 3, line 14	4,5
Y	GB 2 329 786 A (CENTRAL RESEARCH LAB LTD) 31 March 1999 (1999-03-31) page 2, line 4 -page 5, line 21; figures 2,3	4,5

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
5 July 2002	11/07/2002

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/01294

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

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